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11

BREAKDOWN IN THERMAL PLASMAS

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The phenomenon of breakdown or transition in gas discharges, such as from dark discharge to glow or from glow to arc, has been studied by many workers (Meek and Craggs, 1953, Gambling and Edels, 1956, von Engel, 1965) under low and high pressures and temperatures. Recently, due to the engineering developments in the use of high temperature and pressure plasmas for direct energy conversion projects, considerable interest in the study of thermal plasmas is growing amongst scientists and engineers (Kerrebrock, 1963, Ralph, 1963, George 1963, Sakuntala, 1964 and 1965). The present letter deals with a correction relating to the theory given by Sakuntala (1965).

In thermal plasmas described by Sakuntala (1965), the breakdown potentials are considerably lower than the expected values by the general theory. In a gas at relatively high temperature, the plasma is due to thermal ionisation in the hot seed vapour, thermionic emission from the hot electrode surfaces and electron-atom collisions in the gas between the electrodes. Considering these three factors, the space charge limited current at any point x between the electrodes, distant D, can be derived from Poisson's equation,

$$\frac{d^2V}{dx^2} = \frac{-dX}{dx} = 4\pi\left\{\frac{j^-e^{\alpha x}}{\mu^-X} - \frac{j^-(e^{\alpha D}-e^{\alpha x})}{\mu^+X}\right\} \text{ e.s.u} \tag{1}$$

μ^- and μ^+ are electron and positive ion mobilities respectively. V is the potential and X is the field at the point. j^- is the initial electron current from the cathode which is responsible for the ion production.

Integrating (1) twice with the limits $X = 0$ at $x = 0$ and $V = 0$ at $x = 0$, the total current density j at $x = D$ is given by,

$$j = \frac{9}{32\pi} \frac{\mu^- V^2}{D^3} \Big/ 1 - \frac{\mu^-}{\mu^+} \left[1 - \frac{3}{\alpha D^{2/3}} \left(\frac{e^{\alpha D} D^{\frac{1}{2}} - \alpha\phi - D^{\frac{1}{2}}}{e^{\alpha D}} \right) \right] \text{ e.s.u.} \tag{2}$$

where

$$\int e^{\alpha x} x^{\frac{1}{2}} dx = \phi \tag{3}$$

It can be seen that when the denominator in (2) equals zero, the current in the discharge becomes infinite. The integral term ϕ is evaluated by applying Weddle's rule.

Let

$$\eta = \frac{3}{\alpha D^{3/2}} \left(\frac{e^{\alpha D} D^{\frac{1}{2}} - \alpha\phi - D^{\frac{1}{2}}}{e^{\alpha D}} \right) \tag{4}$$

Taking arbitrary values for α, η is calculated for different values of D. Fig. I shows the computed results. From the plots, it can be seen that for any η value, the product αD remains constant. The breakdown occurs when $\eta \approx 1$ for which $\alpha D \approx 10^{-2}$. Neglecting the integral term, Sakuntala (1965) shows that the condition for breakdown is for $\alpha D \approx 3$.

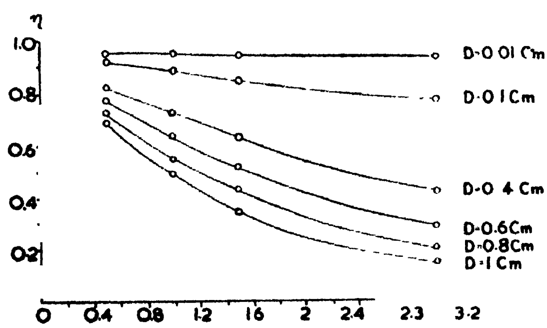

Fig. 1

It should be noted, from the present calculated values, that the integral term is a decisive factor and its value cannot be ignored in comparison to the other terms in (4). This very low value for the productive path αD indicates that ionisation by collisions should occur, within a very short distance from the cathode—probably within the sheath thickness.

A negative fall space or sheath develops in front of the electron emitting Cathode. At the boundary between the fall space and the thermal plasma, the ions cross the boundary by virtue of their velocities. If it can be assumed that this boundary acts as an electrode or probe with a large negative potential with respect to the plasma, the positive ions flowing towards it create a positive space charge. This ensures the neutralisation of the negative space charge and finally at the correct j^+ value the transition to arc takes place.

From the values obtained, it is interesting to note that effective collisions between electrons and atoms in the already diluted fall space can result in the transition to low voltage arc. Due to the presence of a sufficient number of positive ions produced by thermal ionisation, the voltages required for breakdown are much lower than those for a cold gas.[1]

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OBITUARY

Dr. D. B. Sinha

We regret to announce the untimely death of Dr. D. B. Sinha after a brief period of illness. He was a Reader in the Department of Applied Physics, Calcutta University, and also a member of its Senate and Academic Council. Dr. Sinha was connected with this journal for a number of years as a member of its Board of Editors. He was also a past General Secretary and Treasurer of the Indian Physical Society. He obtained his M.Sc. degree in Applied Physics from the University of Calcutta in 1935 and his Ph.D. in 1955 from the University of London working at the Imperial College of Science and Technology. A distinguished educationist himself he was connected with many educational institutions of this city in various capacities. He was also the author of some well known text books in Physics.

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